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Short communication

Corn production on an eroded soil: effects of total rainfall and soil water storage

F.J. Arriaga, B. Lowery*

Department of Soil Science, University of Wisconsin-Madison, 1525 Observatory Drive, Madison, WI 53706-1299, USA

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Abstract

Soil erosion generally causes reduced crop productivity because of degraded soil physical and chemical properties. A long-term study was established in southwest Wisconsin, USA, in 1985 to investigate the effects of past soil erosion on corn (*Zea mays* L.) production. Three levels of erosion (slight, moderate, and severe) of a Dubuque silt loam (fine-silty, mixed, mesic, Typic Hapludalfs) were investigated, as defined by the percent of surface soil remaining. Corn was grown from 1985 to 1999 with small differences in grain yield among erosion levels, but with a long-term trend of decreasing yield with erosion. Average yields were 10.7, 10.3 and 10.3 Mg ha^{-1} for slight, moderate and severe erosion levels, respectively. Based on the 15 years of research it appears differences in grain yields among erosion levels can be attributed mainly to soil water availability. When rainfall was below the 15-year average, grain yield was 12.8, 12.9 and 15.2% less than that of the 15-year average for slight, moderate and severe erosion levels, respectively. Soil water storage increased as erosion severity increased, however more stored water was needed to produce comparable yields with increasing erosion level. Thus, grain production differences among erosion levels from year-to-year can be attributed to weather differences, particularly rainfall.

Keywords: Erosion; Productivity; Water storage; Corn; Rainfall

1. Introduction

Important soil biological, chemical and physical properties for plant production are degraded as a soil erodes, causing a reduction in crop productivity (Lal, 1987). However, the loss of rooting depth, changes in soil particle size distribution, and associated changes in water holding capacity has the greatest impact on soil productivity (Swan et al., 1987; Andraski and Lowery, 1992). Even though intensive farming practices can mask some of the negative effects of erosion on crop production, these practices do not restore the long-term productivity of an eroded soil or improve its quality. Fertilizer provides some remediation to erosion, but topsoil is essential for maintaining optimal plant production (Larney et al., 1995).

Many investigators have attributed poor plant performance on eroded soil to changes in water retention characteristics. Andraski and Lowery (1992) found that the quantity of water held in the soil increased with increasing level of erosion. However, a considerable amount of this water was not available to plants because of a significant increase in clay content with increasing erosion severity in surface soil from the exposed clay residuum present in the soil profile. Others have also concluded that changes in soil physical

* Corresponding author. Tel.: +1-608-262-2752; fax: +1-608-265-2595.
E-mail address: blowery@facstaff.wisc.edu (B. Lowery).

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properties caused by erosion generally decrease crop production (Olson and Nizeyimana, 1988; Fahnestock et al., 1995). Frye et al. (1982) reported that a decrease of about 5% in plant-available water resulted in yield reductions of between 12 and 36%. Similarly, decreases in plant-available water, water use efficiency, and corn yield have been observed with increasing erosion severity (Tenge et al., 1998). This is in accordance with the findings of Mokma et al. (1992), who reported an average decrease in corn yields of 21% for a 5-year period in severely eroded soil compared with a slightly eroded soil. They concluded that the main cause for yield reductions in the severely eroded soil was a deficiency in soil water storage.

Because of changes in soil physical properties, more specifically water retention, the amount and timing of precipitation has a considerable impact on crop yield. Therefore, the effects of erosion on crop production are more pronounced in certain years than in others because of variations in precipitation amounts and patterns (Swan et al., 1987). For example, during years with more rainfall than normal, there is less reduction of crop yield on eroded land, while in years with less than normal rain, yields are reduced more markedly.

Erosion reduces the crop productivity of a soil by altering soil chemical and physical properties, such as water retention. Therefore, rainfall amount and distribution are more critical for rainfed crop production on eroded soils. Additionally, long-term data showing the effects of erosion on crop production are often lacking. For these reasons the objective of this study was to evaluate the effects of soil erosion on corn productivity over an extended period of time. Secondly, we determined the impact of total rainfall amount and soil water storage on corn grain yield variability in eroded soils using a simple regression procedure.

2. Materials and methods

2.1. Study site and agronomic practices

This study was conducted in the drift less region of southwestern Wisconsin, USA, at the Lancaster Agricultural Research Station, University of Wisconsin-Madison (42°52′N, 90°42′W). Soil at the site is a Dubuque silt loam (fine-silty, mixed, mesic, Typic Hapludalfs), which formed in loess underlain by a red clay residuum with a sub-angular blocky structure (Glocker, 1966). The study area was 90 m × 45 m and located on a southwest facing slope with an average slope of 10–14%. In 1985, three levels of past erosion (slight, moderate, and severe) were identified using the depth to the red clay residuum (2Bt2 horizon) as a baseline. Depth to the red clay residuum ranged from 0.45 to 0.95 m. The depth to the red clay residuum was 22 and 53% less for the moderate and severe erosion levels, respectively, than that of slight erosion level. Three plots of 13.7 m × 7.3 m were established lengthwise perpendicular to the slope for each of the three erosion levels. Alfalfa (*Medicago sativa* L.) was grown at this site for 5 years prior to this study. Since 1984, the site has been under continuous corn (*Zea mays* L.). Tillage operations included chisel plowing in the fall and disking in spring. Anhydrous ammonia was applied as preplant N fertilizer, and N, P and K starter fertilizer was applied at planting. Weeds and insects were controlled with pesticides as needed. Fertilizer application was made based on soil test results for the severely eroded plots. This was done in an effort to remove the effects of erosion on soil chemical properties as this study focused on soil physical properties.

2.2. Soil water storage and total rainfall determination

Volumetric soil water content (VWC) measurements were made weekly with a neutron moisture probe (Model 503, Campbell Pacific Nuclear Corp., Martinez, CA) for the 1985–1993 growing seasons, with exception of 1991. Two steel access tubes were installed in each plot to take neutron-probe readings at 15, 25, 50, 75, and 100 cm. Access tubes were located at the lowest- and upper-most rows of each 10 row plot, with one access tube in each of the two rows. Neutron counts were taken until two of the readings at a given depth were within 1% of each other and water content was determined from the average of these values. Two calibration curves were developed near the plot area at five different locations. One calibration curve was needed for readings taken at 15 cm, and the second one for other reading depths (>15 cm). Coefficients of determinations (R^2) for the calibration equations were greater than 0.96. Standard error estimates were 0.015 and 0.012 $m^3\,m^{-3}$ for the 15 and >15 cm soil depth equations, respectively.

Average water storage (AWS) for each growing season was calculated for a 1 m deep profile by averaging the weekly VWC readings for a period of 150 days after planting (DAP_{150}), and then multiplying the average VWC by the soil profile depth. A period of DAP_{150} was considered the most important for crop growth since most corn hybrids, including those in this study, mature at DAP_{110} or earlier.

Rainfall data were obtained from the research farm archive collected by a recording rain gauge located on the station. Precipitation readings were evaluated on a daily basis. Total rainfall amount for each growing season was calculated for DAP_{150} period.

2.3. Harvest and statistical procedures

Harvesting for yield assessment was performed manually on the two center rows of each plot. Corn grain subsamples were collected for water content determination. Total grain weights were adjusted to 15.5% moisture content. Data were analyzed using analysis of variance (ANOVA) applying the generalized linear model (GLM) procedure in Statistical Analysis Systems (SAS) software (SAS Institute Inc., 1989). Means separation was performed using least significant difference (LSD) multiple-range test procedure in SAS.

3. Results and discussion

3.1. Corn yield as affected by erosion severity

Corn grain yields (1985–1999) varied considerably from year-to-year (Fig. 1). For this reason erosion level had no significant effect on the 15-year grain

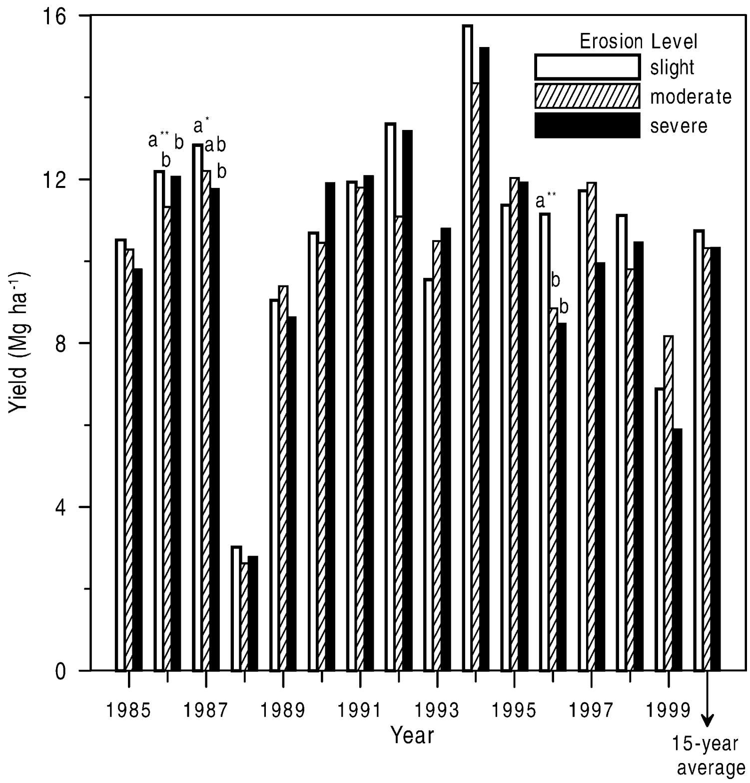

Fig. 1. Corn grain yields from 1985 to 1999 for three erosion levels. LSD yield means separations within years are presented with a lower case letter above each bar. Similar letters show no significant difference between means at the Pr > F reported, where $*$ is $\alpha = 0.05$, and $**$ is $\alpha = 0.10$. Bars without lower case letter are not statistically significant.

yield average. However, the slight erosion level had the greatest average yield for the 15-year period, producing an average yield of 10.7 Mg ha^{-1}, followed by the moderate and severe erosion levels, both producing 10.3 Mg ha^{-1}, suggesting a long-term trend of somewhat decreasing grain yield with increasing erosion level, even with optimal fertilizer applications. Additionally, differences in yields among erosion levels were significant in 1986, 1987, and 1996 at 0.05, 0.10, and 0.05 significance levels, respectively (Fig. 1). For these 3 years, greater yields were recorded for the slight erosion level. In 1986, corn yields between slight and severe erosion levels were not significantly different. In 1987 and 1996 yields were significantly reduced in the severe erosion when compared to the slight erosion level. Agronomic practices have remained fairly constant for the 15-year study period, therefore one can attribute any year-to-year differences in grain production to variations in other factors, such as rainfall and soil physical properties.

3.2. Effect of total rainfall on corn yield

The lack of a consistent trend in corn yield with erosion level is attributed to year-to-year weather variations, primarily rainfall, which is in accordance with the findings of Swan et al. (1987). The year with the greatest recorded corn grain yield was 1994, where rainfall for DAP_{150} (528 mm) was slightly greater than the 15-year average (485 mm) for this area, and the lowest yielding year was 1988 receiving only 259 mm of rainfall DAP_{150} (Figs. 1 and 2). Additionally, average corn yield reductions of 12.8, 12.9 and 15.2% were recorded for the slight, moderate and severe erosion

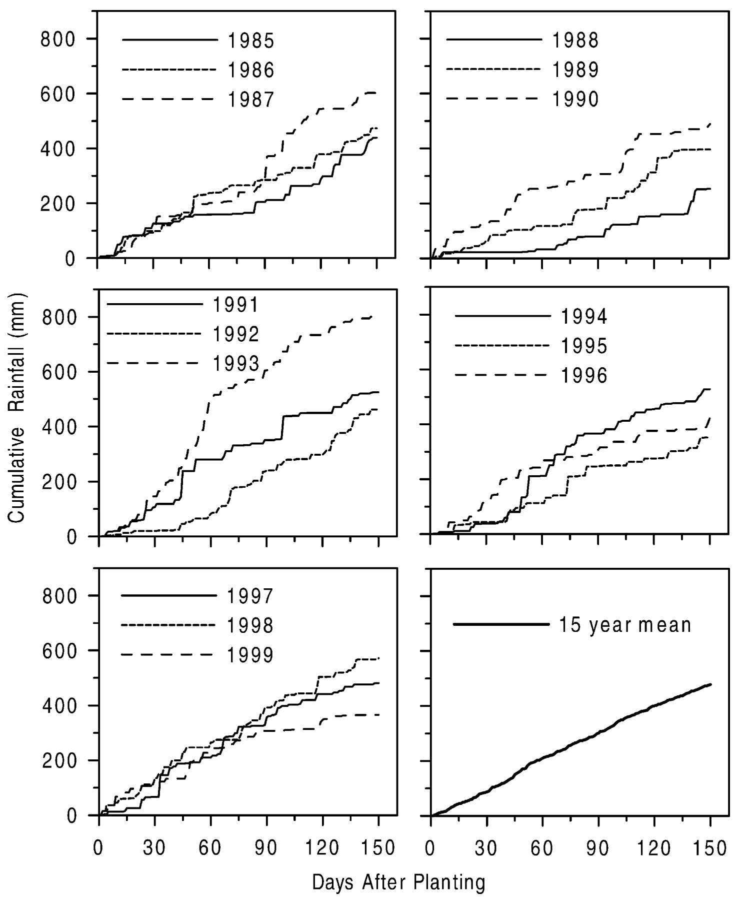

Fig. 2. Cumulative rainfall amounts at the Lancaster site since 1985–1999, and 15-year cumulative rainfall average for a period of DAP_{150}.

levels, respectively, compared to the 15-year average yield when rainfall was below the 15-year average.

Since corn yield was significantly different among erosion levels in 1986, 1987 and 1996, this part of the discussion will focus on these 3 years. April to October rainfall amounts for 1986 and 1987 were similar (632 and 695 mm, respectively), but the DAP_{150} rainfall amount in 1987 (602 mm) was considerably greater than in 1986 (497 mm) (Fig. 2). However, there was more rainfall in the early- to mid-section of the growing season in 1986 than in 1987. These temporal distribution differences of rainfall were the main contributing factor for differences in corn yield trends between the 1986 and 1987 growing seasons. While significant differences were not found, in 8 of the 15 years there were greater yields for the slightly eroded soil. Greater differences would be expected if corn yields from these erosion levels were compared to that of uneroded soils, but unfortunately these data are not available because the entire site has experienced some erosion.

Given the effect of erosion severity on soil water retention and yield (Frye et al., 1982; Andraski and Lowery, 1992; Fahnestock et al., 1995), rainfall amount and distribution were likely the main contributing factors to differences in corn yield between erosion levels. Although no statistically significant relation in corn yield was observed between erosion levels and total rainfall amounts for DAP_{150} in the 15-year study period, it was highly significant ($\alpha < 0.01$) for the period of 1985–1993. Thus, the relationship between erosion level, total rainfall for DAP_{150}, and corn yield was investigated to evaluate the relationship of total rainfall amounts to productivity.

Total rainfall amounts for the DAP_{150} period and corn grain yield followed a quadratic-type relationship (Fig. 3). Rainfall for DAP_{150} of about 600 mm appeared to be optimal for grain production for the three erosion levels, but the production potential decreased with increasing erosion level. Additionally, the curves shift slightly to the right with increasing erosion level. This shift indicates that the moderately and severely eroded areas require an increase of 2.5 and 5% in rainfall, respectively, to achieve their production potential when compared to the slight erosion level.

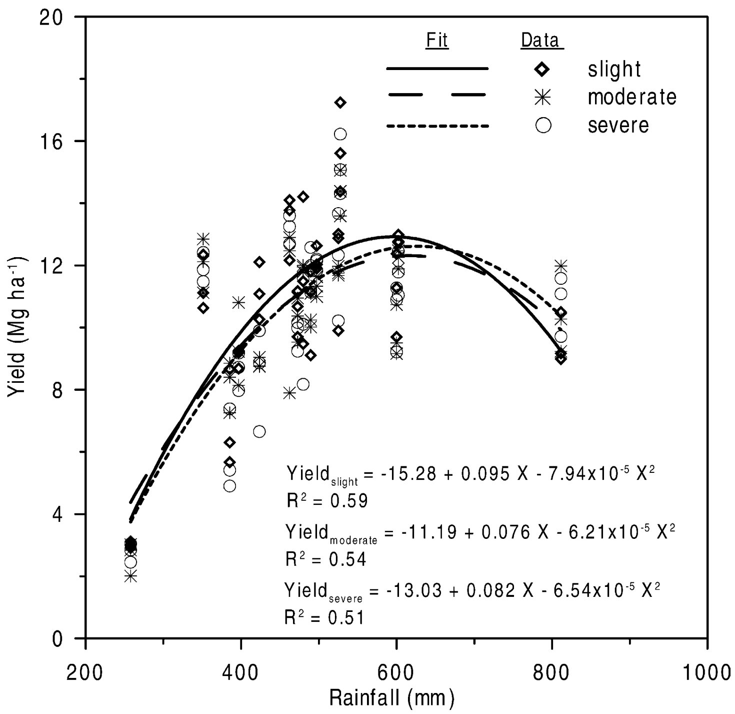

Fig. 3. Relationship of corn yield with total rainfall for a period of DAP_{150} for each erosion level. The $Pr > F$ for all three equations is <0.01.

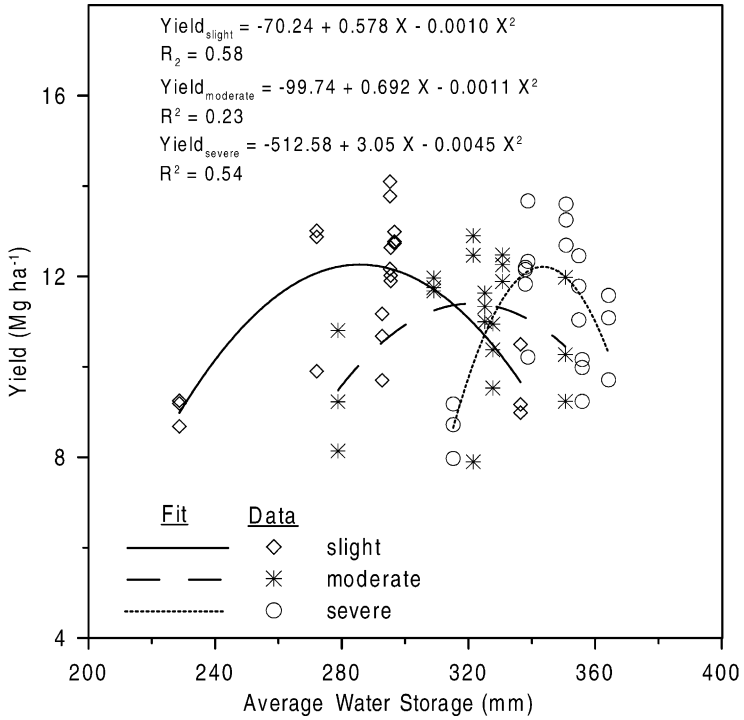

Fig. 4. Relationship of corn grain yield with average soil water storage for a period of DAP_{150} for each erosion level. The Pr > *F* is <0.01 for the slight and severe erosion level equations, and 0.10 for the moderate level equation.

3.3. Soil water storage

Adequate water is essential for plant growth, and consequently soil water storage plays a critical role in crop production. Data available for eight growing seasons show that AWS for DAP_{150} had a significant impact on corn yield ($\alpha = 0.01$) (Fig. 4). There was also a close relationship between erosion level, rainfall, AWS and grain production. Greater AWS for the DAP_{150} period was recorded with increasing erosion level (Fig. 4). Since there was a trend of increasing clay content with increasing erosion level, soils that were more eroded will hold water more tightly making this water less available for plant uptake (Andraski and Lowery, 1992). As with rainfall, the curves shift to the right stressing that more stored water would be needed in the soil to achieve its production potential as erosion severity increases. Also the curves narrow with increasing erosion level suggesting that grain yield was more sensitive to changes in water storage as erosion severity increased. Furthermore, there was significant ($\alpha = 0.01$) interaction between erosion level and water storage on corn yield. These data indicate that more water was stored in the soil with increasing erosion level, but corn yield was reduced. Even though the differences were marginal, total AWS for DAP_{150} period was not as good as a predictor of corn yield as total rainfall, especially for the moderate erosion level.

4. Summary and conclusions

Data presented here demonstrate a relatively simple way of studying the effect of soil erosion on crop productivity as it relates to rainfall amount and soil water storage over a extended period of time. It was found that differences in corn grain yield among the three erosion levels varied from year-to-year. Although not statistically significant, the long term trend was a reduction in grain yield with increasing erosion, even with adequate fertilization. Total rainfall and AWS for a DAP_{150} period had a significant impact on crop yield for the three erosion levels. Corn yields followed a quadratic relationship with rainfall and AWS, but rainfall appeared to be a better yield predictor than AWS. Total rainfall of about 600 mm for the DAP_{150} seems to be optimal for corn production at this research site, with an increase in rainfall between 2.5 and 5% needed as erosion severity increased to achieve optimal yield production. The AWS increased with increasing erosion level but corn yield decreased, suggesting decreased soil water availability. Additionally, it appears that grain production was more sensitive to changes in water storage with increasing erosion level.

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